REMARKS

Claims 1-20 are pending in the application. Claims 8-10 and 18 are withdrawn from consideration. Claims 21-22 were previously canceled.

Statement of Substance of Examiner's Interview

Applicant appreciates the Examiner's courtesy in granting the Interview with the undersigned on September 20, 2004. The Examiner issued an Examiner's Interview Summary Record (PTO-413) following the Examiner's Interview.

In addition to the Examiner's remarks, please review and enter the following remarks summarizing the interview conducted on September 20, 2004:

During the interview, the undersigned discussed the applied references with the Examiner in particular detail consistent with Applicant's previous remarks traversing the rejections. However, the Examiner maintained the obviousness rejection of the pending claims over the combined references to Ming-Jiunn, Ohba, Lee, and Okazaki.

The Examiner emphasized that Ming-Jiunn et al. is the primary reference. The Examiner asserted that Ming-Jiunn satisfies "a gallium nitride (GaN)-based group-III nitride crystal layer having a light-emitting part of hetero-junction structure on said buffer layer". Since Ming-Jiunn does not teach a boron-phosphide buffer layer, the Examiner pointed to Ohba et al. as teaching a boron-phosphide buffer layer. Since Ming-Jiunn does not teach wherein "said second conduction-type surface ohmic electrode is composed of a plurality of electrodes which are disposed on a surface of a region other than the projective region of the pad electrode on said group-III nitride crystal layer, and said window layer covers and is in contact with the surface of

said group-III nitride crystal layer on the entire projective region of the pad electrode", the Examiner pointed to other references for only those specific features.

As to the claimed "plurality of electrodes", the Examiner pointed to Okazaki et al. and clarified that even though Fig. 5(e) may not show a plurality of electrodes, Okazaki's specification discloses the use of a plurality of electrodes: "With reference to FIG. 4, agent layer 13 can comprise a plurality of island shaped portions. A metal layer comprising such island-shape portions can also effectively scatter current." (see Okazaki, Fig. 4, and col. 6, lines 6-9); "Agent layer 45 can also include island-shaped portions as shown in FIG. 4." (see Okazaki, Figs. 6(A)-6(D), and col. 7, lines 57-58). Although Applicant's agent pointed out structural and compositional distinctions over Okazaki such as its lack of a gallium-nitride layer, its discontinuous ITO layer, and its failure to disclose or teach where the "window layer covers and is in contact with a surface of said group-III nitride crystal layer on the entire projective region of the pad electrode", the Examiner emphasized that Okazaki was only cited for its teaching of a plurality of electrodes, and asserted that Okazaki's combination with Ming-Jiunn was proper.

As to the claimed "said window layer covers and is in contact with the a surface of said group-III nitride crystal layer on the entire projective region of the pad electrode", the Examiner pointed to Lee et al. and clarified that he is taking the structure of Lee's conductive transparent oxide layer (60) as being equivalent to Applicants' claimed window layer (see Lee, Fig. 5(a)). The undersigned urged that the oxide layer (60) of Lee must be used in combination with Lee's additional, p-type transparent window layer (56), thus forming a Schottky barrier with the oxide layer (60). As a result, the combination of Ming-Jiunn with Lee would also require

incorporating into Ming-Jiunn's structure an additional window layer on top of Ming-Jiunn's GaN cladding layer (13). However, the Examiner considered that (1) Ming-Jiunn teaches a GaN layer and that Lee's p-type transparent window layer (56) is not required, and that (2) in any case, the present invention would also form a Schottky barrier at the interface of the window layer and the GaN layer. Namely, in the Examiner's view, the fact that Lee teaches a Schottky barrier does not teach away from incorporating only a single window layer of Lee into the device of Ming-Jiunn.

It is respectfully submitted that the instant STATEMENT OF SUBSTANCE OF INTERVIEW complies with the requirements of 37 C.F.R. §§1.2 and 1.133 and MPEP §713.04.

Claim Rejections Under 35 U.S.C. § 112

Claims 1-7, 11-17, 19 and 20 were rejected under 35 U.S.C. 112, second paragraph, as lacking antecedent basis with respect to various limitations in the claims.

Applicant responds as follows.

Claims 1, 11 and 19 have been amended to provide antecedent basis for a/the "surface of said group-III nitride crystal layer". Entry of the amendment is respectfully requested.

Accordingly, Applicant respectfully requests reconsideration and withdrawal of the rejection under 35 U.S.C. § 112, second paragraph.

Claim Rejections Under 35 U.S.C. § 103

A. Claims 1-3, and 7 stand rejected under 35 U.S.C. 103(a) as assertedly unpatentable over Ming-Jiunn et al. in view of Ohba et al., Lee et al., and Okazaki et al., for the reasons of record.

B. Claims 4 and 5 stand rejected under 35 U.S.C. 103(a) as assertedly being unpatentable over Ming-Jiunn, Ohba, Lee, and Okazaki as applied to claim 1 above, and further in view of Bastek, for the reasons of record.

C. Claims 11-13, 16, 17, 19 and 20 stand rejected under 35 U.S.C. 103(a) as assertedly being unpatentable over Ming-Jiunn in view of Lee and Okazaki.

D. Claims 14 and 15 stand rejected under 35 U.S.C. 103(a) as assertedly being unpatentable over Ming-Jiunn, Lee, and Okazaki as applied to claim 11 above, and further in view of Bastek, for the reasons of record.

Applicants respectfully traverse the rejections as follows consistent with Applicant's previous arguments, incorporated herein by reference, presented in the Amendment under 37 C.F.R. § 1.116 filed on March 12, 2004, and in the Response under 37 C.F.R. § 1.114(c) filed on April 19, 2004. Applicant focuses on the rejection of independent Claims 1, 11 and 19.

Each of the Examiner's rejections includes at least a combination of Ming-Jiunn with Lee. Applicant again notes that Ming-Jiunn's window layer 11B does not cover and is not in contact with a surface of layer 13 said to correspond to the claimed group-Ill nitride crystal layer on the entire projective region of pad electrode 10 as required by present Claims 1, 11 and 19. The Examiner asserts Lee for this feature.

Applicant respectfully submits that there is no motivation for combining Ming-Jiunn with Lee. Even if motivation to combine were proper, which Applicant disputes, the combination of Ming-Jiunn with Lee would still not achieve the present invention.

Lee et al., as noted by the Examiner, forms a Schottky barrier at the interface between the conductive transparent oxide layer 60 and the window layer 56 in order to block current underneath contact (pad) 62 (i.e., to mitigate against the current-spreading effect of window layer 56 over the entire surface of the LED). This would seem to suggest arrangement of surface electrodes at a position other than the projective region of the pad electrode (see Lee, col. 4, line 59 to col. 5, line 20). However, this same disclosure in Lee also teaches that window layer 56 is essential in Lee et al., and selected portions of Lee cannot be arbitrarily used to modify the primary reference without also utilizing window layer 56. Further in this regard, in each of Figs. 5 to 8, Lee shows window layer 56 arranged between conductive transparent oxide layer 60 and top cladding layer 544.

Even if the combination of Ming-Jiunn with Lee were appropriate, the present invention would still not be achieved. The sectional view of Fig. 5A of Lee et al. on its face resembles Fig. 3 of the present specification, however, the structural placement and compositions of layers are materially different. For example, unlike in Lee where a Schottky barrier is formed at the interface between the conductive transparent oxide layer 60 and the window layer 56, Applicant points out that the interface of layers 306/305 in Fig. 3 of the present specification does <u>not</u> form a Schottky barrier. That is, layer 58 of Lee et al. is such that only a partial current flows to layer

56 (see col. 4, lines 52-55 of Lee et al.). On the other hand, layer 308 of the present invention homogeneously diffuses the current which flows to layer 305 (see page 14, lines 19-22).

Furthermore, the present specification cites to an article by T. Margalith et al. entitled "Indium tin oxide contacts to gallium nitride optoelectric devices" published in Applied Physics Letters, Vol. 74, No. 26, pp. 3930-3932 (1999) (see page 4, lines 2-14). This article by T. Margalith et al. describes that the interface of the p-GaN layer and ITO forms an ohmic contact (see page 3930, right column, lines 31-32 and Fig. 2(b)).

Also, as required by independent claims 1, 11 and 19, the window layer must cover and must be in contact with the surface of the group - III nitride crystal layer on the entire projected region of the pad electrode. This limitation is not met by Fig. 7 of Ming-Jiunn et al, where transparent window layer 11B is not in contact with clad layer 13. The subject limitation is also not met by any of the figures of Lee, where conductive transparent oxide layer 60 is not in contact with top cladding layer 544. Rather, as discussed in detail above, P-type window layer 56 intervenes. Thus, because neither Ming-Jiunn et al nor Lee et al meets the subject limitation of claims 1, 11 and 19, it is not seen how the combination of the cited two references could ever achieve the invention. Applicant respectfully requests the Examiner to carefully study and reconsider this particular aspect of the rejection.

In the present invention, by disposing a plurality of surface ohmic electrodes at equal intervals in the peripheral region of the pad electrode on the surface of one constituent layer, the device operating current supplied through the window layer from the pad electrode can uniformly flow to the light-emitting part (see page 15, lines 16-20).

On the other hand, if the interface of layers 306/305 were to form a Schottky barrier, as in the combination of Ming-Jiunn with Lee, the device operating current would not uniformly flow to the light-emitting part. Thus, even if proper motivation to combine the references existed, the combination of Ming-Jiunn with Lee would still not achieve the present invention or its specific benefits.

Accordingly, Applicant respectfully requests reconsideration and withdrawal of the above rejections under 35 U.S.C. § 103(a).

Conclusion

In view of the above, reconsideration and allowance of this application are now believed to be in order, and such actions are hereby solicited. If any points remain in issue which the Examiner feels may be best resolved through a personal or telephone interview, the Examiner is kindly requested to contact the undersigned at the telephone number listed below.

The USPTO is directed and authorized to charge all required fees, except for the Issue Fee and the Publication Fee, to Deposit Account No. 19-4880. Please also credit any overpayments to said Deposit Account.

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Indium tin oxide contacts to gallium nitride optoelectronic devices

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We have fabricated GaN-based light-emitting diodes using transparent indium tin oxide (ITO) *p* contacts. ITO-contacted devices required an additional 2 V to drive 10 mA, as compared to similar devices with metal contacts. However, ITO has lower optical absorption at 420 nm ($\alpha = 664\ \mathrm{cm}^{-1}$) than commonly used thin metal films ($\alpha = 3 \times 10^5\ \mathrm{cm}^{-1}$). Uniform luminescence was observed in ITO-contacted devices, indicating effective hole injection and current spreading. © *1999 American Institute of Physics.* [S0003-6951(99)01626-5]

High electrical conductivity and transparency to visible light have made indium tin oxide (ITO) a useful material for transparent contacts to many optoelectronic devices. Rectifying contacts to silicon-, GaAs-, and InP-based solar cells and metal–semiconductor–metal (MSM) photodetectors have already been demonstrated.[1–3] Of particular interest, however, has been the use of a nonrectifying ITO contact as a current-spreading layer in AlInGaP light-emitting diodes (LEDs)[4] and as an intracavity contact in AlInGaAs vertical cavity lasers (VCSELs).[5,6]

Light emitters and detectors based on the ZnSe and GaN material systems and operating in the green, blue, and ultraviolet range of the spectrum are rapidly becoming available, and many could benefit from transparent contacts. However, contacting wide band-gap semiconductors is difficult, and reports of transparent contacts in these systems are scarce. ITO ohmic contacts to ZnSe have been demonstrated,[7] as well as Schottky contacts to *n*-GaN.[8] A transparent, ohmic contact to *p*-GaN would be particularly useful, since the poor lateral conductivity of *p*-GaN precludes the use of a ring contact. We report here the use of ITO as a contact to *p*-GaN, and demonstrate effective current-spreading and low optical loss in the blue/violet wavelength range. We also compare ITO to thin metal for use as transparent contacts.

Two GaN films were used in our experiments—both grown by metalorganic chemical vapor deposition (MOCVD) on sapphire substrates. The layer structure for the first was as follows: 3 μm of silicon-doped GaN, five quantum wells consisting of 5 nm silicon-doped $In_{0.04}Ga_{0.96}N$ barriers and 3.5 nm undoped $In_{0.14}Ga_{0.86}N$ wells, and a 180 nm magnesium-doped *p* layer. The second film had a similar structure only with 7.5 nm GaN barriers and 2.5 nm $In_{0.2}Ga_{0.8}N$ wells, a 40 nm magnesium-doped $Al_{0.2}Ga_{0.8}N$layer, and a thicker *p* layer (300 nm). The dopant level in the *p* layer for both films was around $5 \times 10^{19}\ \mathrm{cm}^{-3}$, and the hole concentration (in bulk material) was approximately $7 \times 10^{17}\ \mathrm{cm}^{-3}$ after activation at 950 °C for 3 min.[9] We note that although the active region differed, the characteristics of the contact should only be a function of the top *p*-layer quality, and as such we can compare similar devices on these two wafers.

The ITO films and contacts were deposited in a dc ring magnetron sputtering system with a target to sample distance of 12 cm, in a 9 mTorr argon/oxygen plasma, with gas flows of 45 and 0.25 sccm, respectively. The target was high density (95%) ITO with an indium oxide to tin oxide ratio of 90/10. The power density at the target was 6 W/cm^2, and the deposition rate at the substrate was approximately 20 nm/min. A liftoff process was used to define the ITO contacts. The deposited films looked dark brown, but became transparent after a rapid thermal anneal (RTA) at 600 °C for 2 min in a nitrogen ambient. Anneals at 500 °C resulted in contacts with higher turn-on voltages and larger leakage currents, while contacts annealed at 700 °C were significantly more resistive. ITO films annealed at all three temperatures exhibited identical optical characteristics (absorption and refractive index).

The ITO thickness was chosen to be 25 nm in order to minimize absorption in the films—a necessity for vertically emitting lasers. Using transmission line method (TLM) patterns, we obtained the bulk resistivity for ITO, $\rho = 5.4 \times 10^{-4}\ \Omega\,\mathrm{cm}$, in good agreement with values reported elsewhere.[10] Additionally, we found that no degradation of the films occurred for lateral currents of up to 300 mA in 50 μm wide stripes.

To verify hole injection, we fabricated broad-area ($200 \times 200\ \mu$m) LEDs with a 25 nm ITO *p*-contact, and for comparison, devices with 5/6 nm Ni/Au instead of ITO. Square Ti/Au probe pads were placed in a corner of the devices. The ITO/Ti/Au *p* contacts were ohmic, with a specific contact resistivity of $3 \times 10^{-4}\ \Omega\,\mathrm{cm}$. Contacts to the *n* layer were Ti/Al/Ni/Au and ohmic. As shown in Fig. 1, the ITO-contacted devices (on the material with thicker *p*-GaN) required 6 V to drive 10 mA. The metal-contacted devices required 2 V less, and had about two thirds of the slope resistance. However, the turn-on voltage varied with device geometry, and the slope resistance did not scale inversely with area.[11] Smaller devices, with a 20 μm diameter circular ITO contact and a ring Ti/Au pad [Fig. 2(b)], showed turn-on voltages of around 7.5 V with a slope resistance of approxi-

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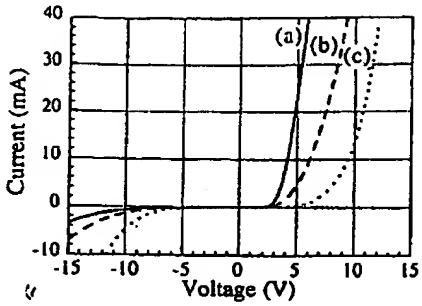

FIG. 1. *I–V* curves of broad area LEDs (200×200 μm) with different *p* contacts: (a) 5/6 nm Ni/Au, (b) 25 nm ITO annealed at 600 °C, and (c) 25 nm ITO annealed at 500 °C.

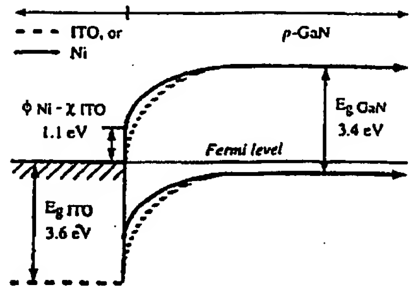

FIG. 3. Equilibrium band diagram schematic for ITO/*p*-GaN and Ni/*p*-GaN. The difference indicated is the work function (ϕ) of Ni minus the electron affinity (χ) of ITO. The band-gap energies (E_g) for GaN and ITO are also noted.

mately 100 Ω. Blue electroluminescence was observed, indicating hole injection into the quantum wells. The luminescence from these devices however, looked spotty.

20 μm diameter devices fabricated on the wafer with a slightly thinner (180 nm) *p*-GaN layer had a higher turn-on voltage. ITO-contacted LEDs turned on around 10 V, with a slope resistance of approximately 190 Ω, and again exhibited a 2 V increase over metal-contacted devices. The luminescence (with peak wavelength of 420 nm and linewidth of 20 nm) was uniform and emanated from underneath the ITO layer, indicating effective current spreading from the ring metal pad to the center of the ITO window. Figure 2 shows a picture taken of a luminescing device. The light intensity exhibited superlinear variation with current, a known phenomenon in GaN LEDs.[11]

Figure 3 shows a schematic of the band structure for the *p*-GaN contacts.[12] Since the work function for nickel is approximately 5.2 eV,[13] while for ITO (a degenerate n^+ semiconductor), the electron affinity is around 4.1 eV,[14] we should expect a voltage penalty of 1 V or less. It should also

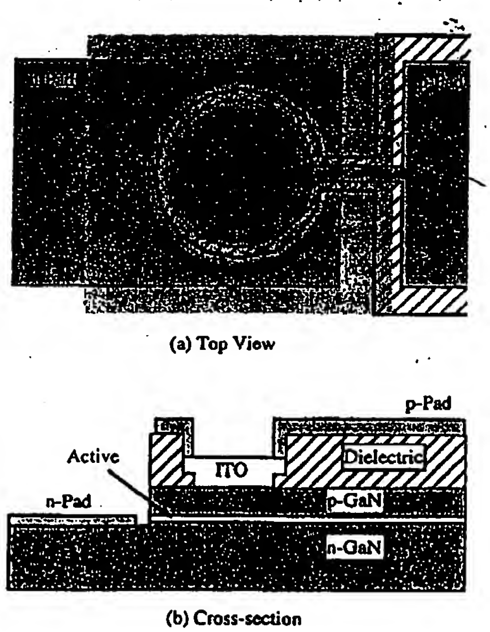

FIG. 2. (a) Overlay of luminescence photo of a 20 μm diameter device on top of schematic. The outer ring luminescence is light scattered from the mesa sidewalls. (b) Cross section of the device.

be noted that the reverse bias characteristics also show a 2 V difference, suggesting the presence of a barrier in either direction. We suspect that on the samples with spotty emission, the regions of increased light emission correlate with regions of low contact resistance. The variations may be due to either nonuniformity in the *p* doping of the GaN, or to a process-related problem such as a partial deactivation of the doping at the GaN surface or formation of a thin gallium oxide layer during the ITO sputtering. We note that *p* doping of GaN is still a developing technology, and that contact to both metal and ITO should continue to improve.

Optical transmission was measured on ITO films deposited on polished sapphire substrates. We have measured both transmission and reflection, from which the loss can be calculated: $T+R+L=1$. The results are shown in Fig. 4, for a 25 nm ITO film, annealed at 600 °C for 2 min, and for a 5/6 nm Ni/Au film. At 420 nm, a typical wavelength for InGaN quantum well lasers, the transmission and reflection add up to 99%. If this loss is completely due to absorption, it corresponds to a power absorption coefficient, α, of 3800 cm^{-1}. However, calculations of α from $R+T$ are prone to error when measuring such thin films (25 nm). A more accurate ellipsometry measurement for this film (on silicon) yielded a refractive index of 2.06 and an absorption coefficient of 664 cm^{-1} ($R+T=99.8\%$), at 420 nm. For comparison, the Ni/Au film had $R+T=65\%$ ($\alpha=3\times10^5$ cm^{-1}) at this wavelength.

In conclusion, we have shown that ITO can serve as an effective current spreading layer, with low optical absorption at 420 nm, providing hole injection into GaN-based light

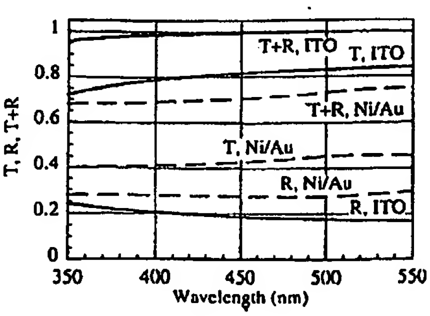

FIG. 4. Reflection, transmission, and sum curves for a 25 nm ITO film (solid lines) and for 5/6 nm Ni/Au (dashed). Both films on double-side polished sapphire.

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emitters. We observed a 2 V increase in operating voltage as compared to a metal contact, higher than predicted by the electron affinity of ITO. We expect that the contact will improve as GaN doping and processing technologies are refined.

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